Assessing Torso Shape and Posture Variations with Flexible Strain Sensors

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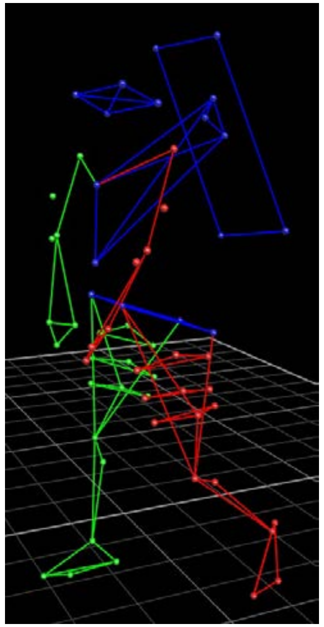
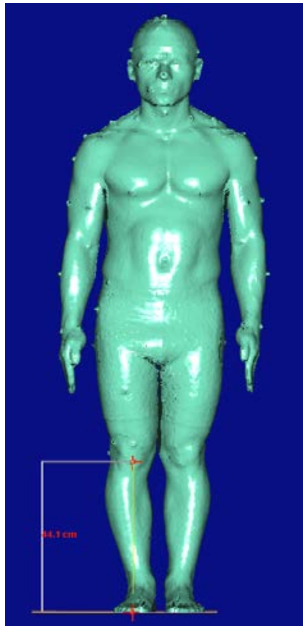
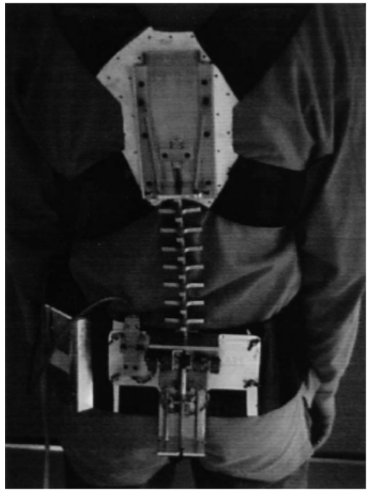
Background

- Human movement inside a spacesuit is largely unknown
  - Kinematic and geometric measurements are required for suit fit and biomechanical analysis during EVA-related tasks
- Constraints of the spacesuit prohibit the use of conventional motion capture or 3-D scanning techniques to capture internal movement
  - Volume restrictions
  - Ferrous magnetic interference







Lumbar Motion Monitor

Xsens MVN suit

Fabric Strain Sensors

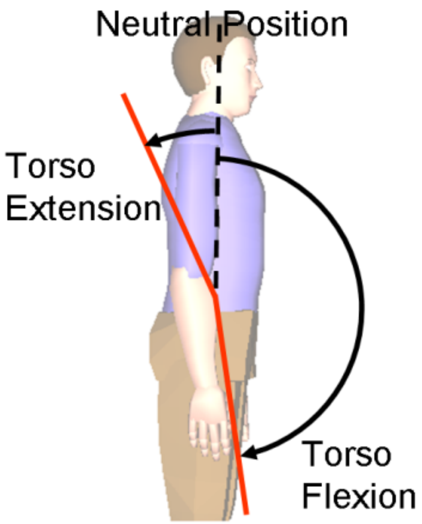
- A newly developed technology using fabric strain sensors can provide useful kinematic information based on overall skin deformation patterns
- **StretchSense Fabric Stretch Sensor**
  - 90 mm × 10 mm surrounded by 2 mm sewable area
  - 80 mm extension available (180% extension of active area)
  - Sensitivity: 1.38 pF/mm
- **Advantages**
  - Low profile
  - Can be adhered to the body or integrated into a garment

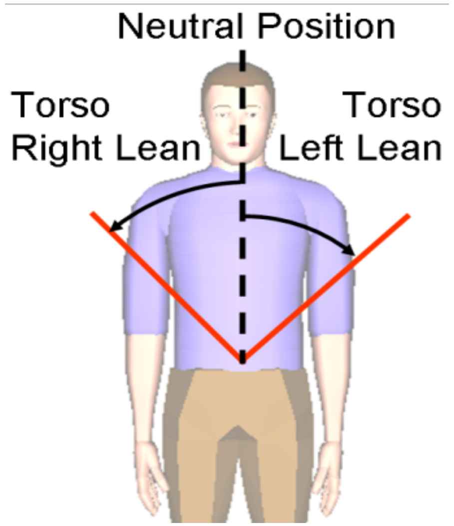
Objective

Develop and test a method for measuring torso shape and posture variation using StretchSense strain sensors

Specific Aims

1. Estimate upper body posture





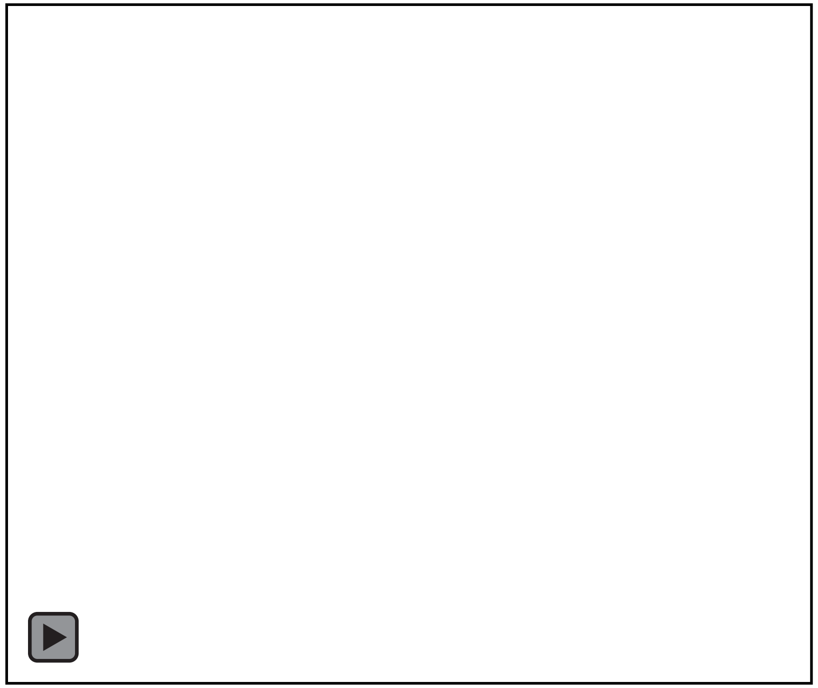
2. Estimate upper body shape

Study Participants and Setup

- 12 active and healthy male participants
- Within healthy BMI ranges (23 - 24.9)
- Age 21 - 52 years
- **Setup**
  - Blue paper stickers are placed on anatomical landmarks
  - Sensors are adhered with Kinesotape

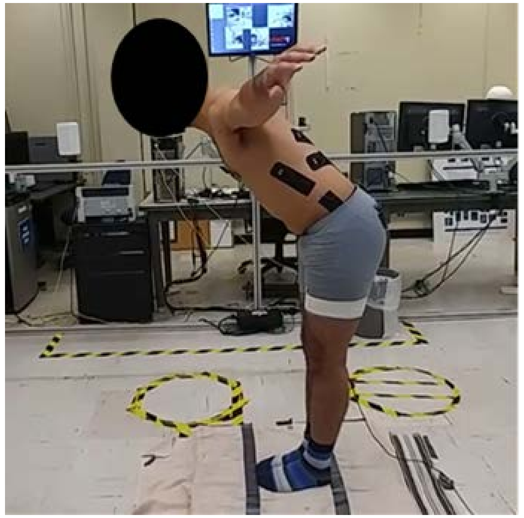
3D scans of all subjects

Body Scanning

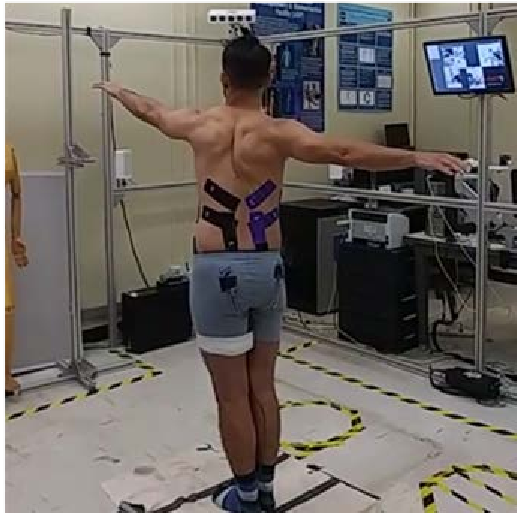


3dMDbody System

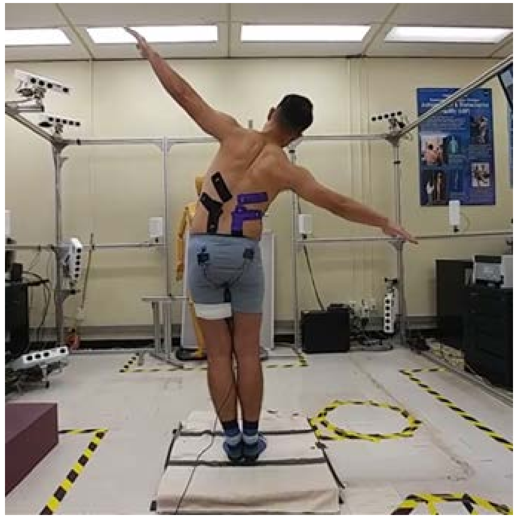
12 full-color camera units
~0.8 seconds capture speed
Error: <0.5 mm RMS



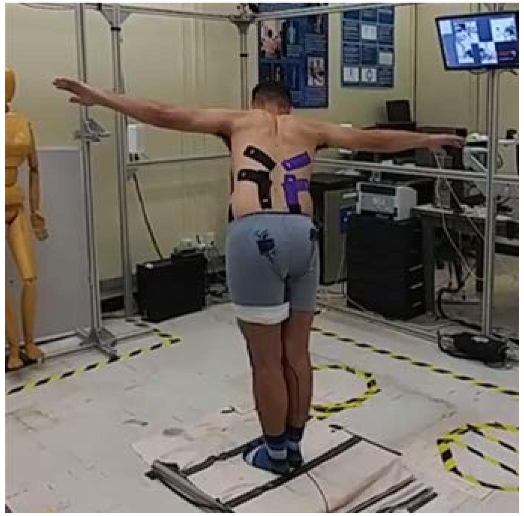
Sagittal Flexion



Axial Rotation



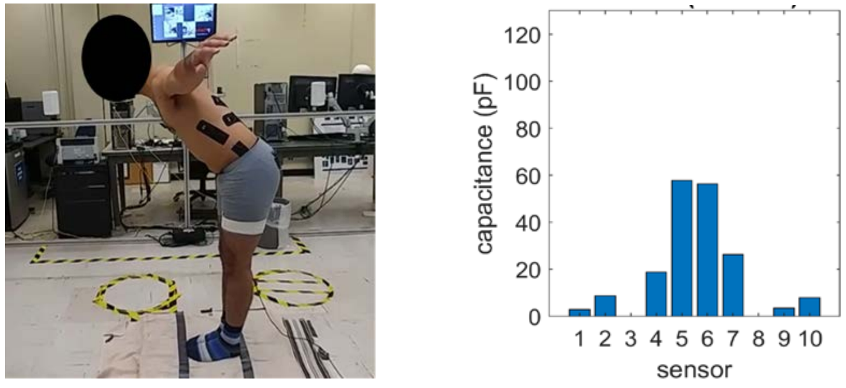
Lateral Bending



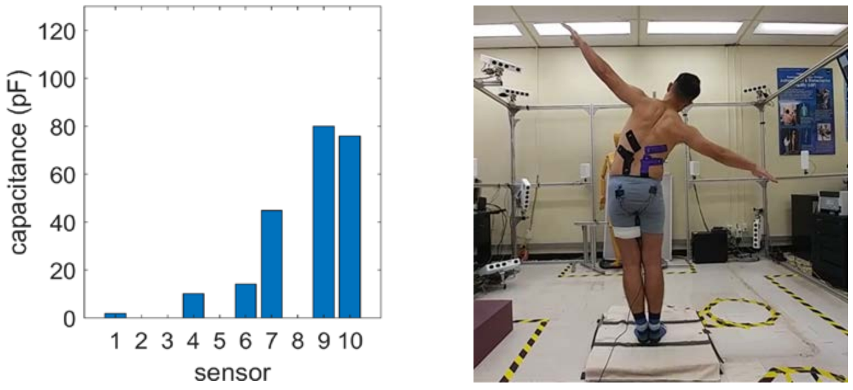
Complex

192 total scans were collected
(12 participants × 8 postures × 2 replications)

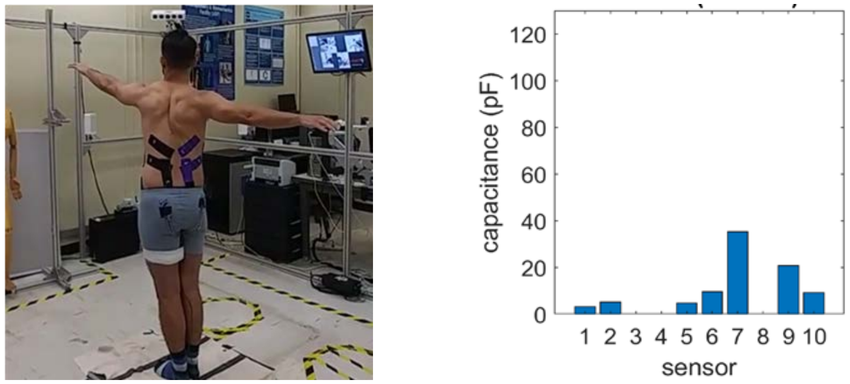
Sensor Activation Patterns are Characteristic to Posture Variations



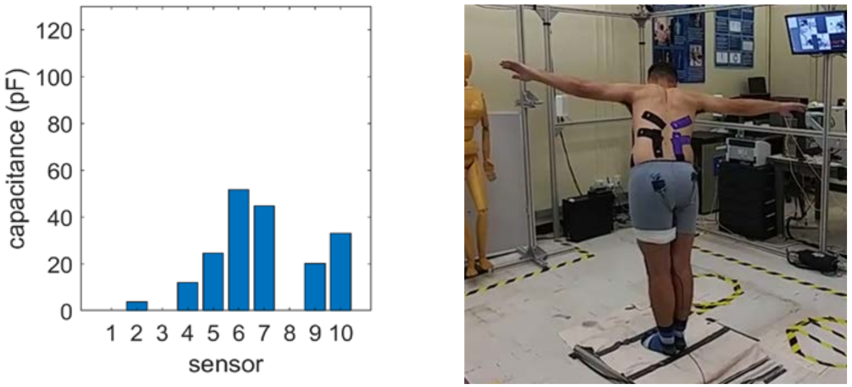
Sagittal Flexion



Lateral Bending



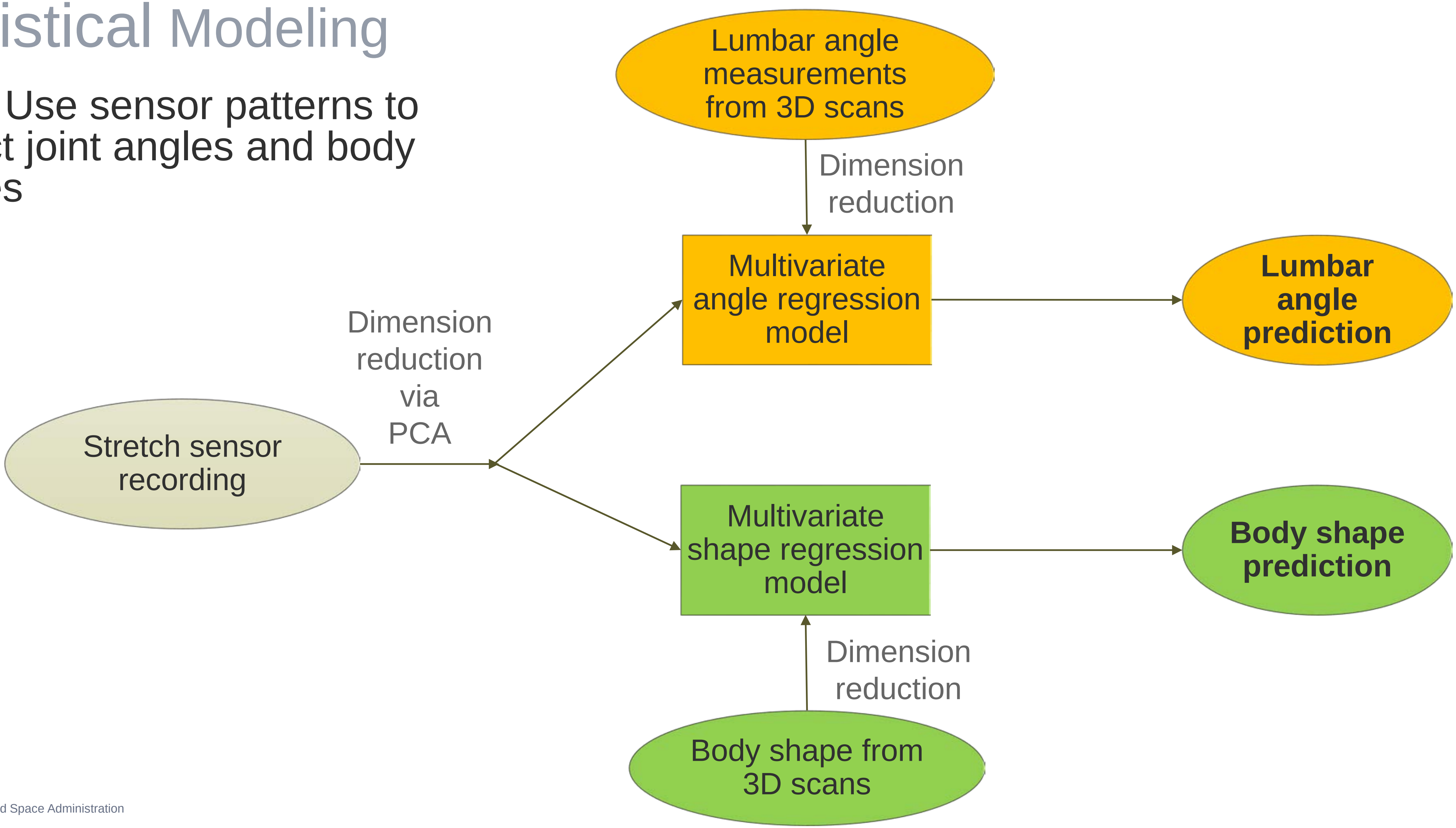
Axial Rotation



Complex

Statistical Modeling

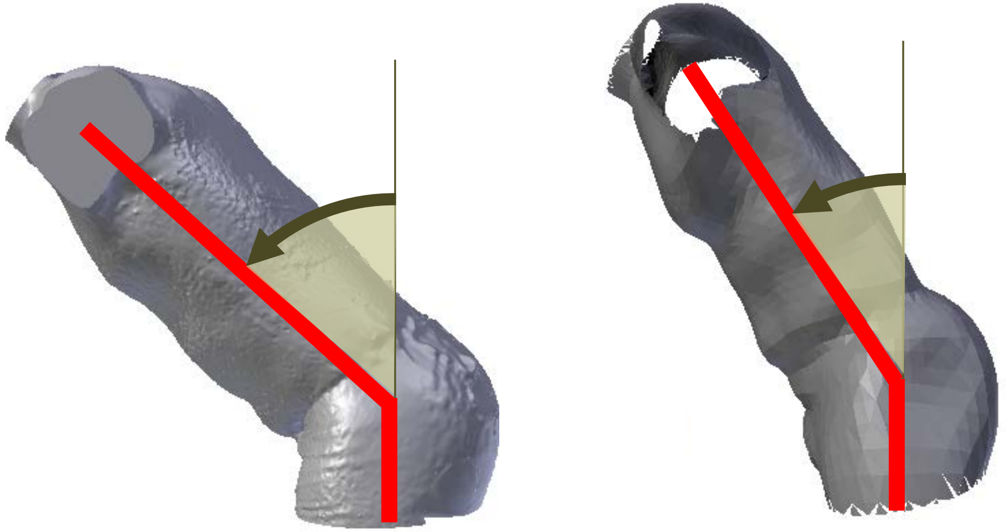
Goal: Use sensor patterns to predict joint angles and body shapes



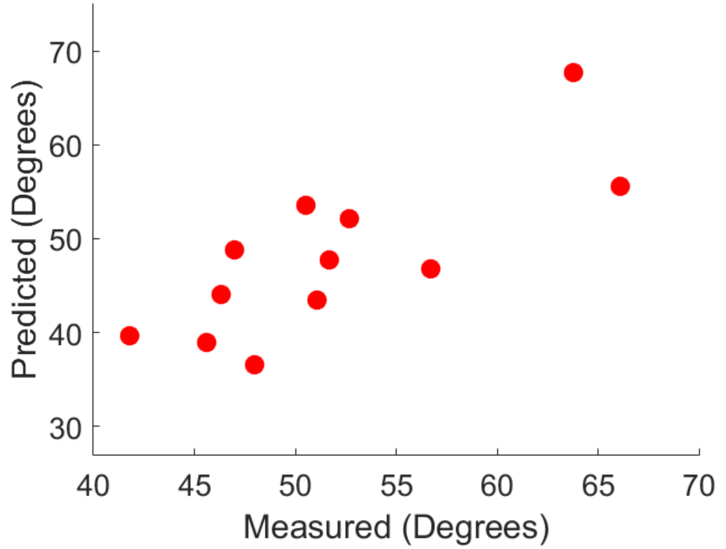
Posture Prediction

Posture		Average Lumbar Angle Estimation Error
Flexion		6.1°
Lateral Bending		5.7°
Rotation		12.4°
Complex	Flexion	8.5°
	Lateral Bending	11.6°
	Rotation	14.9°

Flexion Example



51.1° Measured   43.5° Predicted



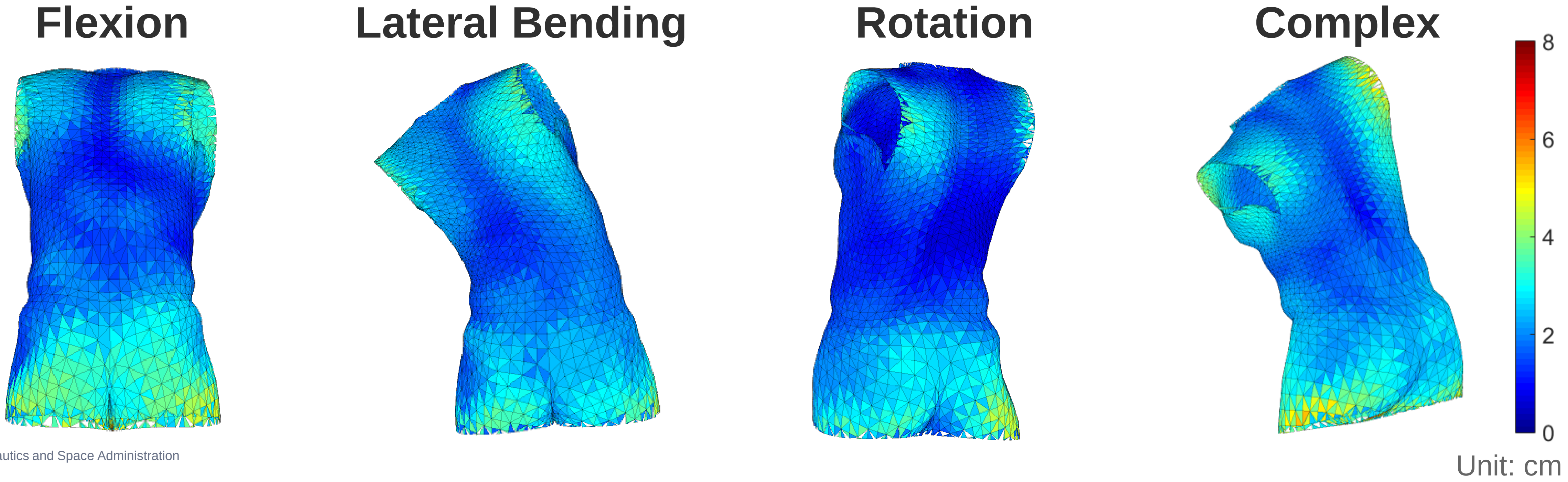
Upper Body Shape Prediction

- Predicted torso shape showed overall good agreement to the scan geometry
- Estimation accuracy was greatest at lumbar subregion (between S1 and T12)
- Shoulder and pelvis regions showed lower prediction accuracy

Average Vertex RMSE

	Torso	Lumbar
Flexion	2.20	0.56
Lateral Bending	2.01	0.51
Rotation	1.95	0.49
Complex	2.26	0.50

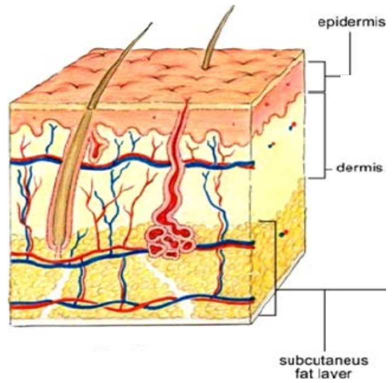
Unit: cm

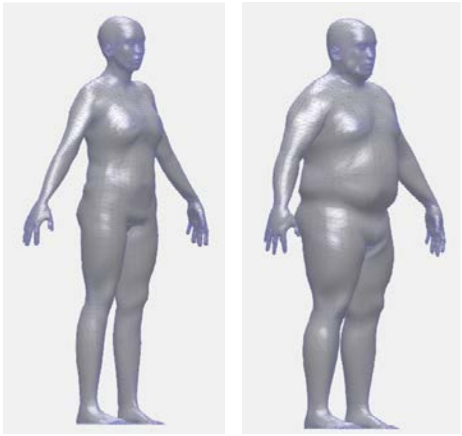


Demonstration

Possible Limitations

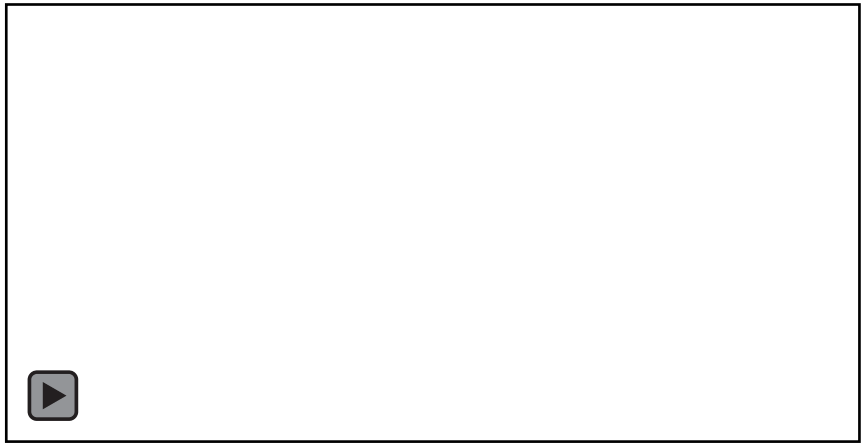
- Sensors could be affected by geometric and biomechanical variations of skin and garment surface
- The model was constructed using specific body types
    - Estimation accuracy may vary for females or individuals with more adipose tissue
- How the sensors would interact with a spacesuit needs investigation
    - High temperature and humidity
    - Physical contact and pressure
    - Sensor robustness



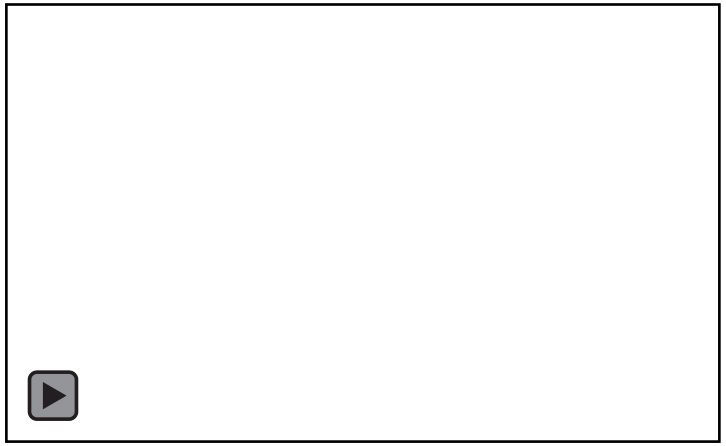


ICA Project Overview: Wearable Sensor Garment

- Objectives and procedures are similar to the previous work
- Sensors are embedded into a wearable garment to measure internal suited motion
- A real-time software tool is created to collect sensor data
- Model is constructed to predict lumbar joint angles and body shape



Sensor integration



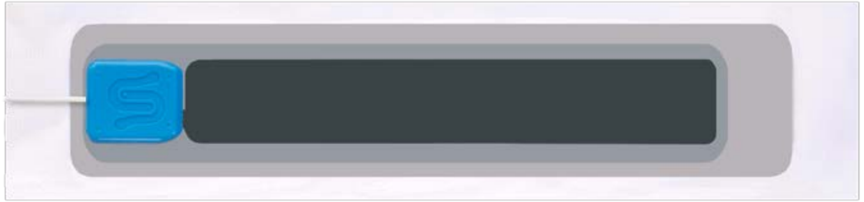
Real-time Software Tool

Future garment implementation

Wearable Sensor Garment Materials

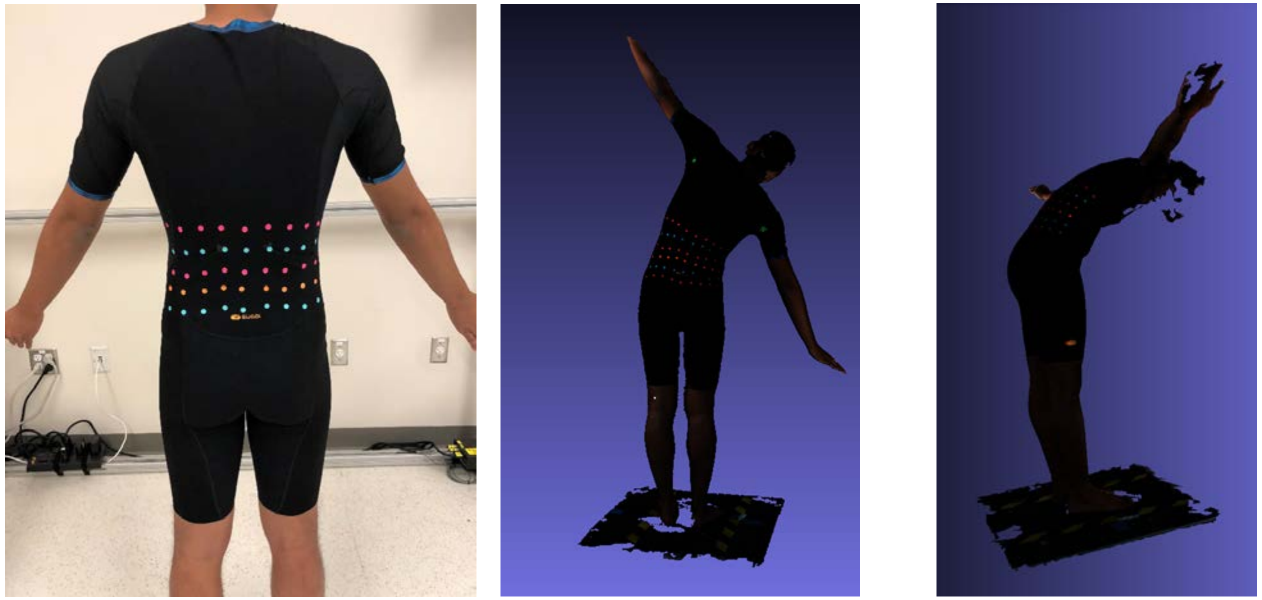
- SUGOI™ triathlon compression garment
  - 71% nylon, 29% spandex

- StretchFABRIC Sensing Element sensors
  - Stretch Sensor
  - 80 x 10 mm silicon sensing zone with Lycra fabric backing
  - Sensitivity: 9.5 pF/mm
  - Greater precision and robustness in comparison to previous sensors

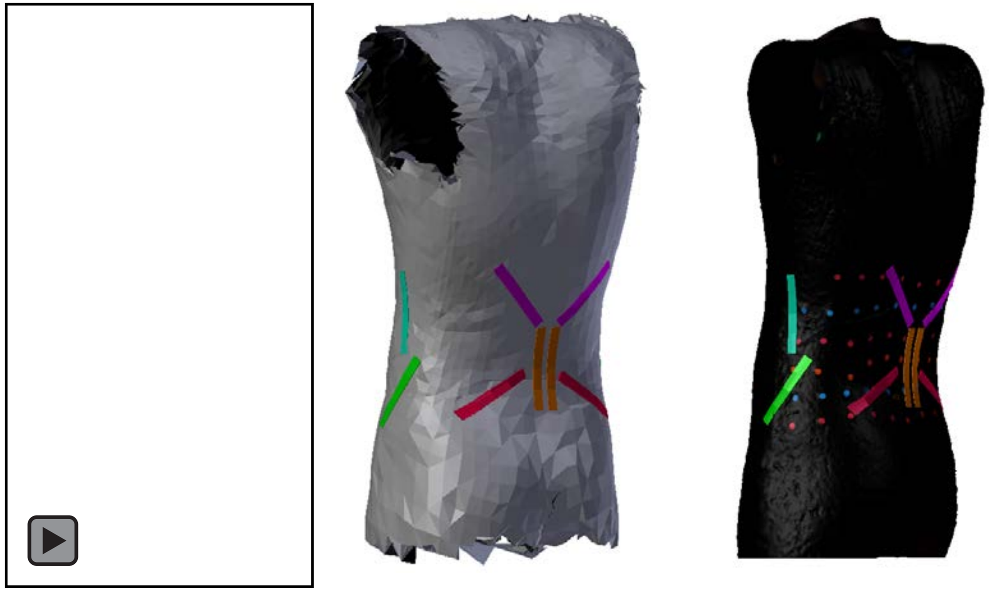


Wearable Sensor Garment Design

- SUGOI™ triathlon compression garment
- Multiple sensor placements were simulated in order to maximize sensor signal variance between postures



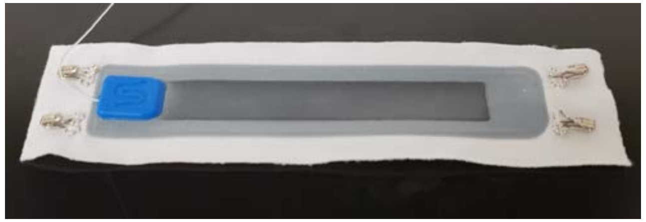
3D Scan Data Collection with Garment



Virtual Sensor Placement

Wearable Sensor Garment Construction

- Sensors were attached to the garment via clasps
- Sensor configuration and data collection software were tested
- Sensor reliability results were encouraging



StretchSense Sensor with Clasps

Sensor Garment Pilot Testing

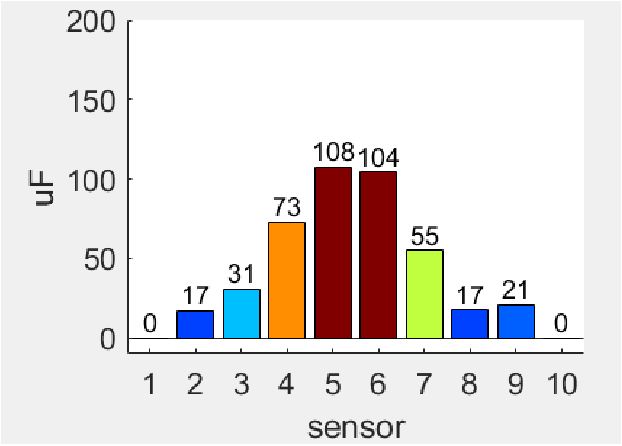
Posture	Average relative SD across all sensors
Flexion	6.8%
Lateral Bending	4.2%
Rotation	12.5%
Complex	7.6%

Unit: μF

Wearable Sensor Garment Testing

- Scan and sensor data from five subjects was collected from16 different static postures
- Post-processing, model development, and data analysis is still ongoing

Sensor Configuration



Sensor and Scan Data

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